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STUDIES FOR SUPERSONIC CRUISE AIRCRAFT  
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**SYSTEMS INTEGRATION STUDIES  
FOR SUPERSONIC CRUISE AIRCRAFT**

**By Vincent R. Mascitti**

**September 1975**

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# NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

## SYSTEMS INTEGRATION STUDIES FOR SUPERSONIC CRUISE AIRCRAFT

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### SUMMARY

In the past three years, significant technical progress has been made in each of the disciplinary research areas affecting the design of supersonic cruise aircraft. The NASA AST/SCAR program has supported three major airframe companies and an independent NASA study team in the integration of these technical advances into supersonic cruise aircraft configuration concepts. While the baseline concepts reflect differing design philosophy, all reflect a level of economic performance considerably above the current foreign aircraft as well as the former U.S. SST. Range-payload characteristics of the study configuration show significant improvement, while meeting environmental goals such as takeoff and landing noise and upper atmospheric pollution.

### INTRODUCTION

The National Supersonic Transport Program was canceled in 1971 after a considerable investment of the nation's resources, both material and human. One of the major factors which contributed to the program's demise was the configuration's economic deficiencies due to marginal range-payload characteristics. In the same time period, economically attractive subsonic wide-body aircraft were being introduced into the long-haul aircraft market. The anticipated performance of the former SST was a direct result of the demonstrated technologies which existed at that time. At the close of the program, it was clear to both Government and industry that significant improvement in supersonic technology was required to make a second generation aircraft economically viable.

With the prospect of the introduction of foreign supersonic transports in the mid-1970's, the nation is in danger of losing its leadership in the long-haul aircraft market if these aircraft proved to be economically successful. Consequently, in 1972, NASA initiated an Advanced Supersonic Technology Program. The intent of the program was, and still is, to give the industry of the country the technology option to proceed with a second generation development of a supersonic transport, if and when that decision is made.

Initially, study contracts were issued with The Boeing Company, the Lockheed-California Company, and the Douglas Aircraft Company to identify and

assess the impact of new technology on the concepts and characteristics of supersonic aircraft. Shortly thereafter, NASA accelerated technology programs in the principal disciplines of propulsion, aerodynamics, structures, materials, and flight controls.

The purpose of this summary report is to present the results to date of the work funded under the AST/SCAR aerodynamic performance technology subprogram system integration studies. Initial findings of the technology assessment studies are included as well as follow-on work in the area of airframe system studies and configuration refinement.

## SYSTEM STUDIES SCOPE

The system studies area of the overall AST/SCAR program includes the integration of inputs from all technical disciplines into practical aircraft concepts through analytical means, configuration layouts, propulsion integration, and weight and balance calculations. The area is also concerned with the identification of technology voids, which are in turn fed back to the individual disciplines for guidance and new program formulation. The process is illustrated in Figure 1. With Government assistance and financial support, new technology breakthroughs emanating from the individual technology programs can be incorporated into configuration concepts and benefits assessed. The rigid, multidisciplinary industry approach to vehicle integration provides the only practical test of the value of a technical idea.

Because of the importance of studying complete configurations, the system integration portion of the overall AST/SCAR program has been a substantial part of the total program. A summary of contractual effort in the integration area is shown in Table I. Design and integration teams have been maintained in the major commercial airframe companies (The Boeing Company, Lockheed-California Company, Douglas Aircraft Company). In addition, a team has been maintained in the LTV Aerospace Corporation (Hampton, VA), under a nonpersonal contract, which works under the close supervision of Langley management.

During the first-year effort, study contracts were issued with the major commercial aircraft companies. These technology impact studies consisted of three tasks defined below:

Task I - Technology Assessment: Assess technology state-of-readiness and potential technology advances necessary to substantially impact the performance of supersonic cruise aircraft.

Task II - Market Analysis: Determine basic market characteristics (probable optimum payload, total fleet size, and number of aircraft required annually) of an AST in the 1980-2000 time frame.

Task III - Concept Refinement and Engine Coordination: Define baseline configuration concepts and identify major problem areas by discipline and by integration among disciplines.

Subsequent current and future contracts continue the iterative process of defining economically and environmentally acceptable advanced supersonic cruise aircraft concepts utilizing the most promising new technologies.

Results of initial and follow-on studies are presented in the next section.

## SYSTEM STUDIES RESULTS

### First-Year Effort (References 1, 2, 3)

Task I.- Results of the initial two-month study on technology needs are summarized in Figure 2 and related to the factors which affect aircraft performance.

An expanded low-speed aerodynamic data base for highly swept, low aspect ratio wings would result in improved takeoff and landing performance, reduced noise, and weight. Improved characteristics obtained by advanced mechanical or propulsive lift devices could facilitate the choice of the highly swept, subsonic leading-edge arrow wing, known for superior cruise efficiency. Typically, takeoff and landing constraints tend to oversize the low aspect ratio arrow wing, resulting in a significant performance decrement.

Similarly, FAR Part 36 noise restrictions tend to oversize the propulsion system, resulting in large weight penalties due to both the bare engine and its structural integration. In addition, cruise performance suffers due to a poor engine-airframe match.

New structural concepts, advanced materials, and active control systems promise significant potential for weight reduction. An all-composite structural system could result in an empty weight savings of 10 percent, which leads to a gross weight reduction of about 25 percent for a given range and payload when realized. Advanced titanium fabrication and forming techniques could significantly affect the cost of an advanced supersonic transport.

Task II.- A six-month study was conducted by the three contractors, with airline company inputs, to assess the market potential of an advanced supersonic cruise vehicle for the 1980-2000 time frame. Major results of that study are shown in Figure 3. In order to arrive at these results, estimates were required in defining a route system, probable aircraft utilization, projected traffic, and other competitive aircraft in the fleet. A matrix of combinations of payloads and range capability was studied. Return on investment was found to be insensitive to payloads of 250 to 300 passengers, and ranges of 3500 to 4300 n.mi.. An advanced technology supersonic transport has the potential of capturing 46 percent of the U.S.-Europe market and 34 percent of the U.S.-Pacific market in the year 1990. As indicated in Figure 3, costs (in 1972 dollars) could be twice to three times the B-747 price. Depending on the projected growth in the long-range market, 350 to 1500 aircraft may be required by the year 2000. The reader should be

cautioned that Task II results were obtained at a time when aviation fuel cost was typically 12 cents/gallon. According to a Douglas study, tripling fuel cost has the effect of decreasing the market by 15 percent.

Task III.- Under this effort, conceptual designs of supersonic cruise configurations were studied and baseline concepts chosen. Aerodynamic designs included consideration of low-speed, transonic and supersonic flight regimes, propulsion integration, and drag predictions including interference effects of primary components. Performance analyses of various configurations for realistic mission flight profiles were required. Advanced structural design methods, concepts, and materials were used, which included thermal considerations, loads predictions, structural and fatigue allowances, aeroelasticity, dynamic response, and weight analysis. Coordination between airframe and engine companies (under contract to NASA-Lewis) was necessary to include the effects of external and internal aerodynamic consideration of complete inlet-engine-nozzle configurations.

Figure 4 summarizes the results of the study. All contractors identified the subsonic leading-edge arrow-wing concept as their baseline concept. The choice was not without qualification. The problem area of low-speed performance required attention. The performance potential of the concept is severely compromised by heavy engines located in the conventional trailing-edge position. Oversized engines may be required to meet FAR Part 36 noise goals. The inability to predict aeroelastic characteristics early in the preliminary design cycle was identified as a major problem area for any concept.

The first year's effort can be summarized as follows:

- A large potential market (350 to 1500 aircraft) will exist in the 1980-2000 time frame for a required second generation supersonic transport.
- Range-payload characteristics are 3500 to 4300 n.mi. and 250 to 300 passengers.
- The aircraft must meet operational and environmental restrictions of noise and pollution, and operate from existing international runways.
- Concepts employing the arrow-wing configuration have the potential of meeting the above requirements.
- Significant technology advancement must, however, be incorporated in the design.

#### Follow-on Effort (Reference 4)

Boeing.- Drawing on the experience and data base generated by the past national SST program, Boeing has reopened consideration of the delta-wing concept. Recent aerodynamic improvements are shown in Figure 5. A blended wing-body concept is employed which provides a 13 count reduction in wave drag.

Design Mach number is reduced from 2.7 to 2.4 with an associated reduction in drag-due-to-lift for the supersonic leading-edge wing. The resulting lift-to-drag ratio is 8.9 at  $M = 2.4$  compared with 7.5 at  $M = 2.7$  for the former SST.

As a result of the coordination in the first year's effort between The Boeing Company and Pratt and Whitney Aircraft Company, engine performance goals were established. Boeing's interest in the variable cycle engine potential for subsonic cruise flexibility led to a close working relationship between the two companies. Some 25 variable cycle arrangements were studied which incorporated dual valves and single valve concepts. The latest rear valve engine, designated VCE-112B, indicates a 40-percent range improvement over a heavy dual valve cycle initially studied. The original performance goals are shown in Figure 6 by the shaded bands. The solid lines show results for the 700 PPS VCE-112B engine. Although shortfall exists in acceleration thrust and subsonic cruise and hold fuel consumption, climb and supersonic cruise sfc are well within the goals, as is engine weight.

The noise goal is achieved if coannular noise relief is assumed. Coannular noise reduction is achieved with the outer flow at much higher velocities than the inner flow, which is opposite to the conventional dual stream nozzle, as shown in Figure 7. General Electric and Pratt and Whitney have conducted small-scale static jet noise tests of coannular nozzles under contract to NASA-Lewis. Both contractors have verified noise reductions of 10 EPNdB compared to a conical nozzle having the same thrust. The full-scale flight validation of this phenomena could lead to engine cycles and sizes with no performance penalty due to noise.

Boeing's progress is summarized in Figure 8. Subsonic leg range is plotted versus total mission range. Aerodynamic and propulsion improvements show a supersonic range increase of 1100 miles compared with the former SST. The efficient subsonic cruise of the variable cycle engine provides no range penalty for subsonic operation. This flexibility could substantially increase the available market for advanced supersonic aircraft.

Lockheed (Reference 5).- The main thrust of the Lockheed configuration effort has been to drive down aircraft wing size and weight, and therefore cost. As a result of progress in the area of structural integration and materials, while under contract to NASA-Langley's Structures Directorate (Reference 6), a 15-percent reduction in structural weight is projected. The advanced structure includes composites, advanced bonding techniques, and active controls. The revised baseline concept is shown in Figure 9. The reduced weight helps the low-speed problems of the arrow wing to the point where significant reduction in wing size is achieved. The over-under engine arrangement frees the trailing edge for high lift devices, provides inlet isolation from unstarts, and may facilitate propulsive lift. Folding tips are added and leading-edge sweep reduced to improve low-speed performance. Design Mach number is reduced to  $M = 2.55$  from 2.7 to ease low-speed problems and facilitate the use of composite reinforcement.

The beneficial effect of reducing wing size on the payload capacity is shown in Figure 10. A portion of the drag reduction associated with the

smaller wing can be traded to increase fuselage size to permit six-abreast seating. Payload is increased to 290 passengers.

Lockheed's motivation in the above resizing is mainly economic. Their measure of success is the ratio of aircraft productivity to first cost. New aircraft entering the fleet should show significant improvement in this parameter over existing aircraft to be economically attractive. Figure 11 shows Lockheed's progress in terms of productivity/cost ratio. Impressive gains are shown, but significant range has been traded for payload.

Douglas (References 7, 8, 9, 10).- In the early stages of the AST/SCAR program, Douglas recognized the need for a near-term AST effort. A successful Concorde in service in 1976 could create public enthusiasm for a longer range supersonic transport. This near-term approach has weighed heavily in the formulation and refinement of the Douglas concept.

As a result, near-term preference of an  $M = 2.2$  concept to reduce risk was established. Results of Douglas' cruise Mach number studies are summarized in Figure 12. Douglas' market studies during the Phase II first-year effort indicated that North Atlantic routes would be the prime market for a near-term aircraft. On these shorter routes (3050 to 3500 n.mi.), Douglas feels that the block time differential between  $M = 2.2$  and  $M = 2.7$  was small (20 min - New York to Paris) and did not justify the additional risk which an  $M = 2.7$  concept would entail.

Drawing heavily on the  $M = 2.7$  arrow-wing aerodynamic data base developed by NASA-Langley, an  $M = 2.2$  concept was designed. At this writing, Douglas is conducting supersonic and transonic tests at NASA-Ames to validate their concept at the lower Mach number. Expected aerodynamic performance is shown in Figure 13. Lift-to-drag ratios are 9.0 and 9.5, somewhat below SCAT 15F data because of predicted configuration compromises necessary to incorporate oversized engines which meet FAR Part 36 noise goals.

Douglas has conducted extensive studies to define the  $M = 2.2$  arrow-wing concept, including: arrow- vs. delta-wing planform study to optimize performance, an aerodynamic-structural weight trade study to determine wing area and thickness, an inlet development study which led to the choice of an axisymmetric external compression inlet, and aerodynamic-structural trade to optimize nacelle location.

The current Douglas concept has been generated with a goal of equaling DC-10-30 total operating costs, as shown in Figure 14. The Douglas concept has a significant advantage in operating cost and range-payload as compared to the Concorde, nearly equaling the DC-10-30 while offering about three times the speed.

Rockwell (Reference 11).- While the prime objective of the AST/SCAR system studies program is to improve range-payload performance of supersonic cruise aircraft, attention must be directed to satisfying environmental concerns such as takeoff and approach noise. With a view toward satisfying current FAR Part 36 noise goals as well as more stringent goals contemplated

for the future, a propulsion integration study was conducted by Rockwell International Corporation.

A Multimode Integrated Propulsion System (MMIPS) was studied in an advanced arrow-wing concept. The system took advantage of different arrangements of turbofan and turbojet components which operate as a turbofan at takeoff and landing for low noise and as a turbojet at cruise for low sfc's. Twenty cycle variations were studied which included variations in number of nacelles/airplane, number of engines/nacelle, number of satellite turbojets/fan, fan bypass ratio and pressure ratio, cycle pressure ratio, and turbine inlet temperature. For each system engine cycle performance, aircraft installation and wave drag and engine/aircraft weight were estimated. The aircraft was sized consistent with the following ground rules: NASA-Langley baseline arrow-wing configuration, 2.7 Mach number, 3500 n.mi. range, 234 passengers, 10500-ft takeoff field length, FAR Part 36 noise rules, thrust margin,  $T/D = 1.2$  at  $M = 2.7$ , 60000-ft altitude, and FAR 121.648 reserve fuel requirements. The figure of merit was takeoff gross weight relative to a baseline turbojet cycle with suppressor. The baseline turbojet was provided by Pratt and Whitney Aircraft (Model 5A) resulting from NASA-Lewis' advanced engine studies.

The most promising MMIPS arrangement featured a four nacelle arrangement with one turbofan and one satellite turbojet per nacelle. Results shown in Figure 15 indicate a lower aircraft weight for the MMIPS cycle when noise levels of less than FAR Part 36 - 4dB are imposed.

LTV Aerospace Corporation (References 12 and 13). - Parallel to the configuration refinements efforts of Boeing, Lockheed, and Douglas, NASA-Langley conducts a concept refinement and evaluation effort with the assistance of LTV-Hampton Technical Center. The NASA/LTV generated Reference Configuration has been used throughout the AST/SCAR program disciplines to focus technology improvements.

The incorporation of technology advances into a study airplane configuration has been a tradition at Langley. Aerodynamic advances such as supersonic area rule, variable sweep wings, wing twist and camber, wing-body blending, and sonic boom estimation have been underscored by application to study aircraft. One promising concept, a subsonic leading-edge arrow-wing configuration, was studied in depth by Boeing during the national SST program in 1968. The configuration was designated 336-C.

In defining a reference configuration for AST/SCAR program, problem areas defined by Boeing for the 336-C in 1968 were addressed. Configuration changes are summarized in Figure 16. Design requirements as follows:  $M = 2.7$ , 4000 n.mi. range, 10500-ft takeoff field length, 1.2 thrust margin at 2.7, 60000-ft altitude, FAR 121-648 reserves, and FAR Part 36 noise rules. Major areas addressed in the study are aerodynamics, stability and control, propulsion, weights, noise, and performance.

Range-payload performance of the current baseline configuration is shown in Figure 17. Results of the Boeing 1968 evaluation and the Concorde are

shown for comparison. Significant performance improvement is shown compared with 1968 results, especially in view of the inclusion of hot day performance, FAR Part 36 noise rules, and more stringent reserve requirements.

The reference configuration discussed above was also used as a starting point for a study to determine the impact of liquid hydrogen fuel on supersonic cruise aircraft. Design requirements for LH<sub>2</sub> concepts were the same as those for the JP-fueled reference configuration.

The scope of the investigation included the effects of:

- o Aircraft volume vs. L/D
- o Propulsion sizing and integration
- o Wing sizing
- o Large body stability effects
- o Landing gear configurations
- o Fuel volume and tank integration
- o Takeoff and landing profiles
- o Sonic boom signatures

Three liquid hydrogen configurations were studied as shown in Figure 18. The major difference in the configuration is the degree to which fuel is contained in the wing. Results of the study are summarized in Figure 19. Substantial reductions in gross weight are realized for the LH<sub>2</sub> concepts.

However, operating weights are increased due to large fuselage sizes and special tankage to accommodate the cryogenic fuel. Due to these structural weight penalties, the LH<sub>2</sub> configurations showed small reductions in energy consumed per seat-mile compared to the JP reference aircraft.

In contrast to the results of the NASA/LTV study are those obtained by Lockheed under contract to NASA-Ames (Reference 14). The Lockheed study utilized a JP baseline configuration containing 234 passengers (an earlier version of the NASA reference configuration described above), incorporating duct-burning turbofan engines, and composite materials in six percent of wing and five percent of fuselage. The Lockheed hydrogen configuration carries all the fuel in the fuselage in two large tanks fore and aft of the passenger compartment. Due to the reduced gross weight of the hydrogen configuration, wing size was reduced to 6880 ft<sup>2</sup> (10822 ft<sup>2</sup> for JP configuration). The large differences in the two studies, as shown in Figure 19, are representative of studies which are conducted with differing ground rules and design approaches. For example, the payload and structural weight differences alone can account for the discrepancy in gross weight of the hydrogen configurations. Currently, efforts are being made to explain the discrepancies in detail.

## CONCLUDING REMARKS

In the past three years, significant technical progress has been made in each of the disciplinary research areas affecting the design of supersonic cruise aircraft. During this period, the NASA AST/SCAR program has supported three major airframe companies and an independent NASA study team in the integration of these technical advances into baseline supersonic cruise aircraft configuration concepts. While the studied baseline concepts reflect differing philosophy as to timing, cruise speed, degree of assumed technology, etc., all reflect a level of potential performance considerably above the current Anglo-French Concorde and Russian TU-144 and the former U.S. SST configuration. Based on still incomplete studies, the baseline concepts which have evolved appear to have 20- to 40-percent greater range than the Concorde with some 45- to 100-percent increase in payload fraction; they are considerably quieter than the current and prior SST's and meet FAR noise requirements for their weight class; and they consume some 30 percent less fuel per passenger mile than the current and prior SST's.

The above performance improvements represent an exciting advance in the "state of the art" of supersonic cruise aircraft technology. Even more impressive gains are on the horizon. The successful application of advanced titanium fabrication techniques in the B-1 program could cut airframe cost in half and reduce structural weight by 10 percent. The large-scale validation of coannular noise relief could result in airframe-engine sizes uncompromised for noise. Improved low-speed performance by powered lift is currently under study, with a view toward decreasing wing size and improving cruise airframe-engine match. The last two items alone represent a potential range increase of approximately 1000 n.mi. when applied to the NASA baseline configuration.

It is clear that an aggressive technology program is the key to a successful SST program in the future. The advances identified herein have resulted from a program with substantially less funding support than was originally envisioned.

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TABLE I  
SYSTEMS INTEGRATION STUDIES CONTRACTS

NUMBER	TITLE	COMPANY	TIME FRAME	COST
NAS1-11940	Studies of the Impact of Advanced Technologies Applied To Supersonic Transport Aircraft	Lockheed-California Company	Oct. 1972-Feb. 1975	\$ 650K
NAS1-11939	Studies of the Impact of Advanced Technologies Applied To Supersonic Transport Aircraft	Douglas Aircraft Company	Oct. 1972-Oct. 1973	\$ 399K
NAS1-11938	Studies of the Impact of Advanced Technologies Applied To Supersonic Transport Aircraft	Boeing Commercial Airplane Company	Sep. 1972-Oct. 1973	\$ 469K
NAS1-13612	Technology Application Studies for Supersonic Cruise Aircraft	Douglas Aircraft Company	Oct. 1974-Jan. 1976	\$ 378K
NAS1-13557	Technology Assessment Studies Applied to Supersonic Cruise Vehicles	Lockheed-California Company	Nov. 1974-Nov. 1975	\$ 342K
NAS1-13229	Engine/Airframe Compatibility Studies	Douglas Aircraft Company	Jun. 1974-Mar. 1975	\$ 124K
NAS1-13553	Advanced Supersonic Configurations Using Multicycle Engines For Civil Aircraft	Boeing Commercial Airplane Company	Oct. 1974-July 1975	\$ 398K
NAS1-12245	Study of a Multimode Integrated Propulsion System In An Advanced Supersonic Transport	Rockwell International Corporation	Apr. 1973-Feb. 1974	\$ 137K
NAS1-13500	Non-Personal Services Support Contract	LTV Aerospace Corporation	July 1972-July 1975	\$ 733K
TOTAL				\$3630K

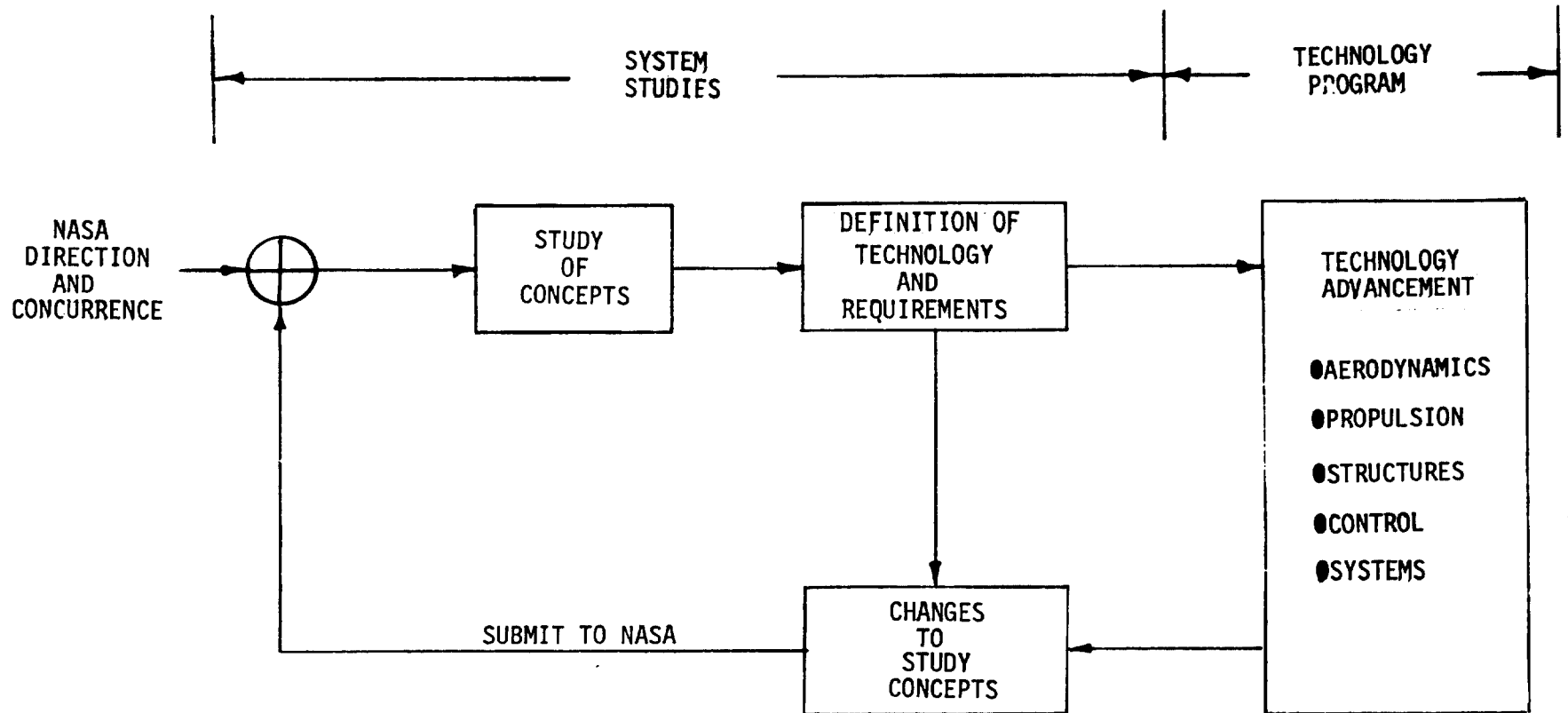


Figure 1. Function of systems integration studies

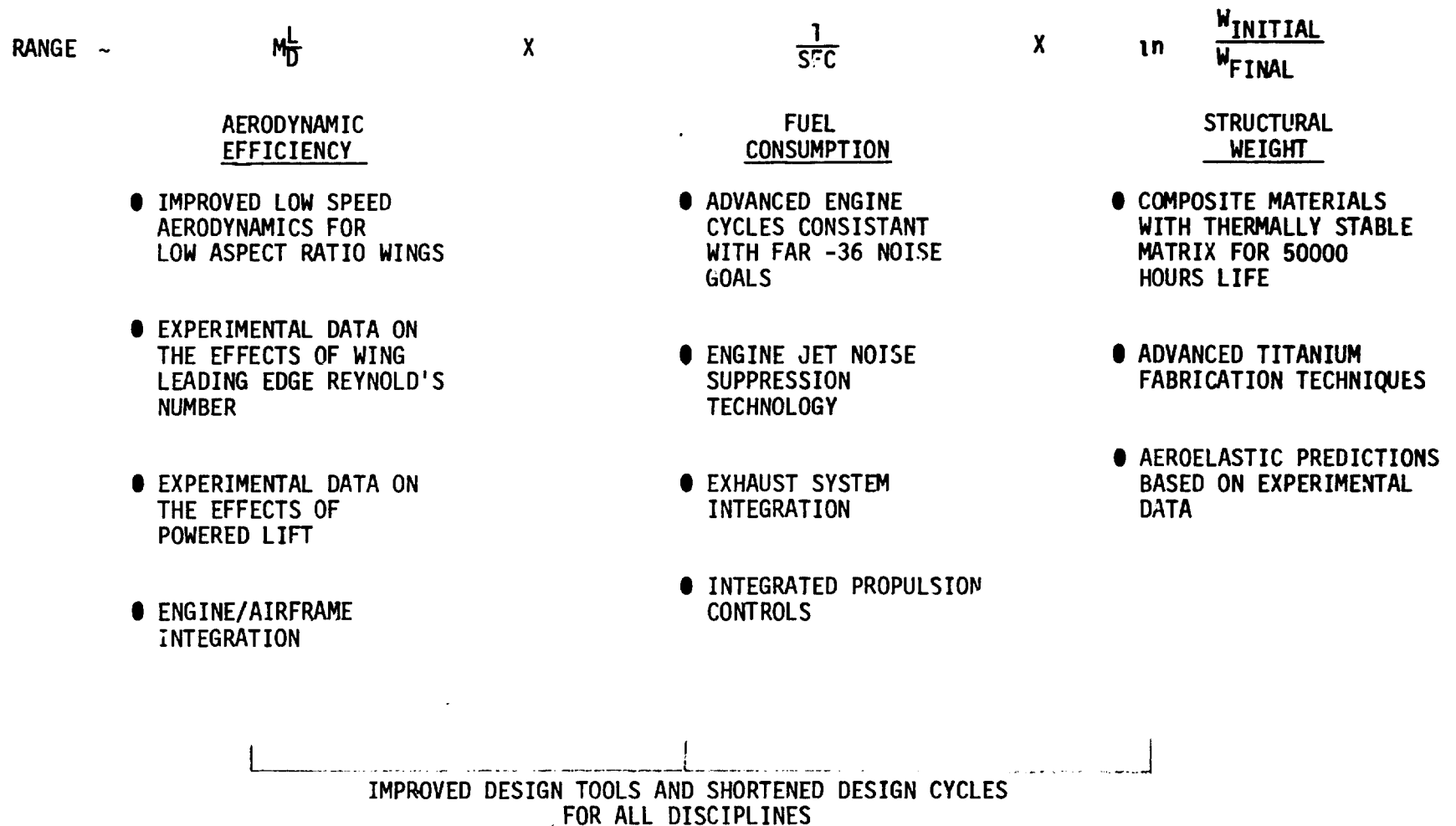


Figure 2. Task II - Technology needs

RANGE = 3600/3700 N.M.

CAPACITY = 250-300 PASSENGERS

BY YEAR 2000

<u>COMPANY</u>	<u>MACH NUMBER</u>	<u>PRICE EACH</u>	<u>TOTAL NUMBER</u>	<u>LONG RANGE MARKET</u>
BOEING	2.7	\$64M* (TITANIUM)	500	50%
DOUGLAS	2.2	\$45M (ALUMINUM & TITANIUM)	350-1500	12%-50%
LOCKHEED	2.7	\$78M (TITANIUM) \$54M (COMPOSITE)	755	35%

\* 1972 DOLLARS

Figure 3. Task II - Market analysis

	BOEING	DOUGLAS	LOCKHEED
CRUISE	2.7	2.2	2.7
WING	SUBSONIC LEADING EDGE SWEEP TRAILING EDGE	SUBSONIC LEADING EDGE SWEEP TRAILING EDGE	SUBSONIC LEADING EDGE SWEEP TRAILING EDGE
ENGINE INSTALLATION	AXI-SYMMETRIC	TWO-DIMENSIONAL AND AXI-SYMMETRIC	AXI-SYMMETRIC
AIRCRAFT SIZE, PASS.	270	270	258-308
MATERIAL	TITANIUM AND COMPOSITES	ALUMINUM AND TITANIUM	TITANIUM AND COMPOSITES
STUDY EMPHASIS	AIRCRAFT SYSTEM THERMAL BALANCE CONTROLS	MATERIALS PROCESSES MANUFACTURING MAINTENANCE	ENGINE LOCATION ENGINE INTEGRATION
PROBLEM AREA	PERFORMANCE LOSS TO MEET FAR-36 NOISE RULES	LACK OF EXPERIMENTAL DATA BASE FOR M2.2 DESIGN	POSSIBLE FLUTTER HAZARD

Figure 4. Task III - Concept selection and refinement

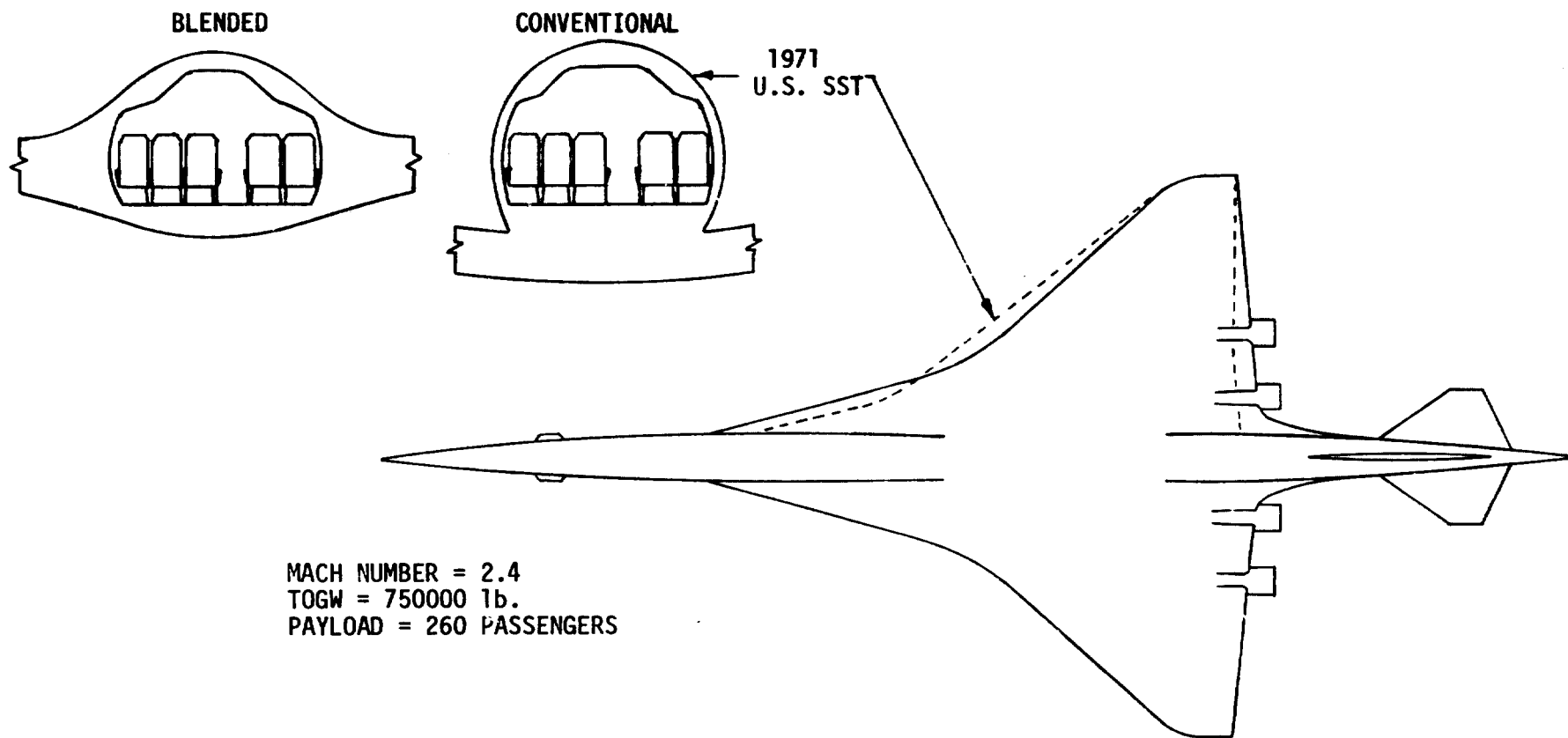


Figure 5. Boeing baseline configuration

<u>ENGINE</u>	<u>WEIGHT</u>
OBJECTIVE	13800 lbs.
VCE-112B	13670 lbs.

NOISE OBJECTIVE  
FAR-36 WITHOUT WEIGHT FOR  
PERFORMANCE PENALTY

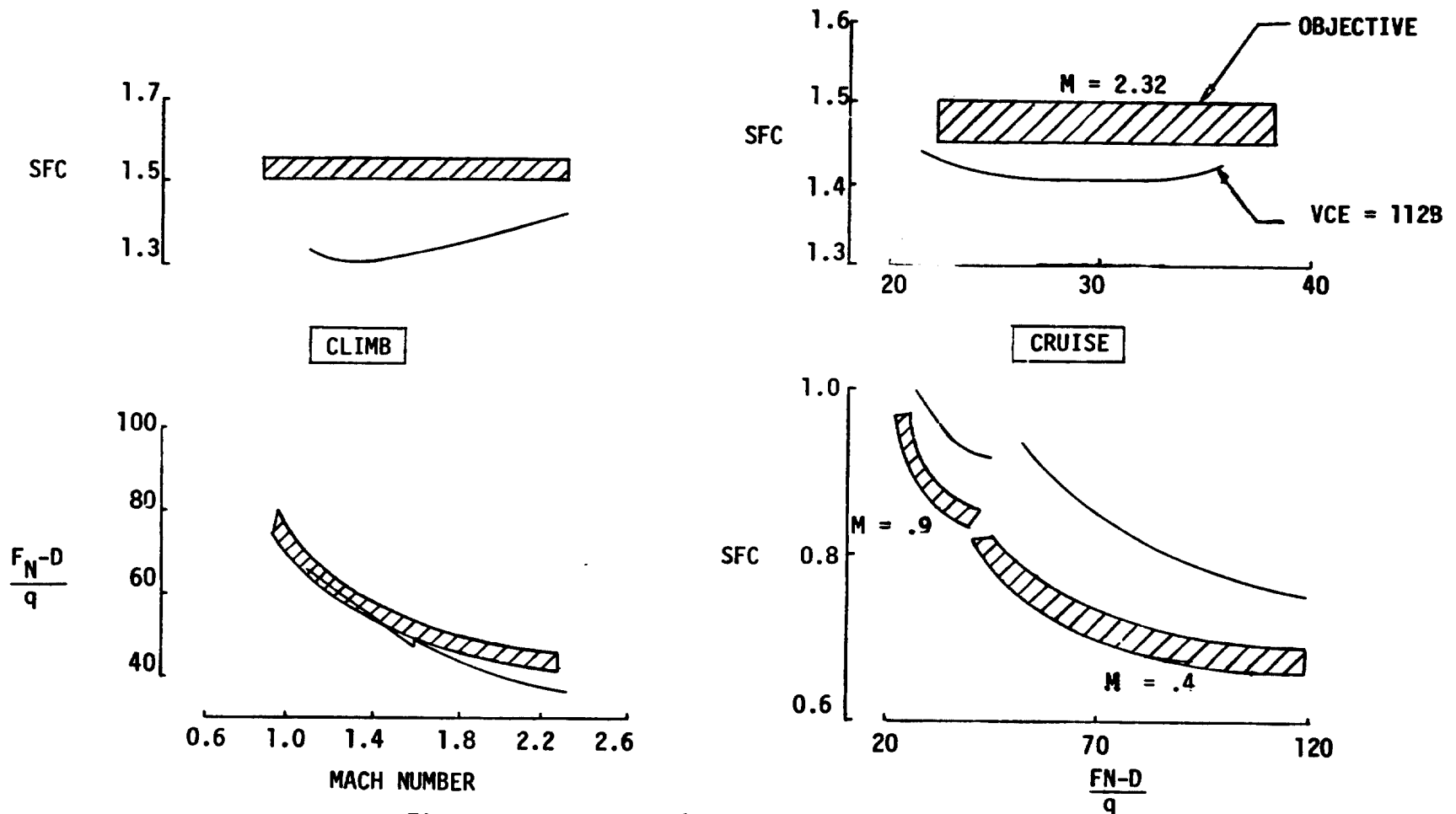
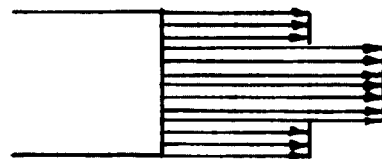


Figure 6. Boeing/Pratt-Whitney propulsion objectives

# CONVENTIONAL COANNULAR



# INVERTED COANNULAR

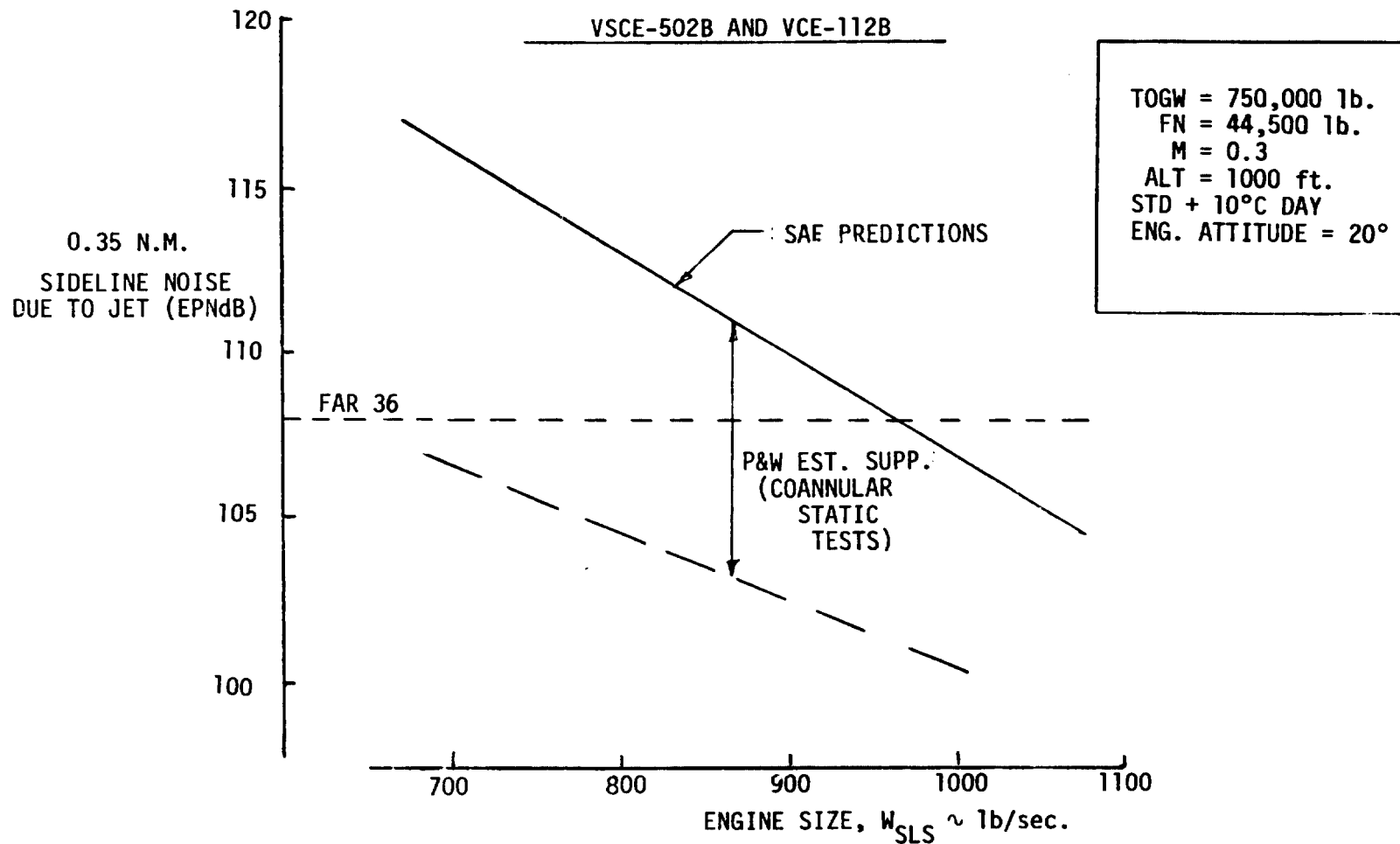
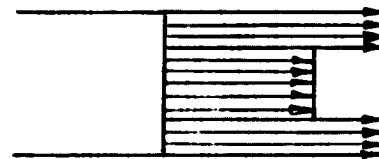


FIGURE 7.- BOEING/PRATT & WHITNEY ESTIMATED IMPACT OF COANNULAR NOISE RELIEF ON ENGINE SIZING.

TAKE-OFF GROSS WEIGHT = 750000 lbs.  
PAYLOAD = 260 PASSENGERS

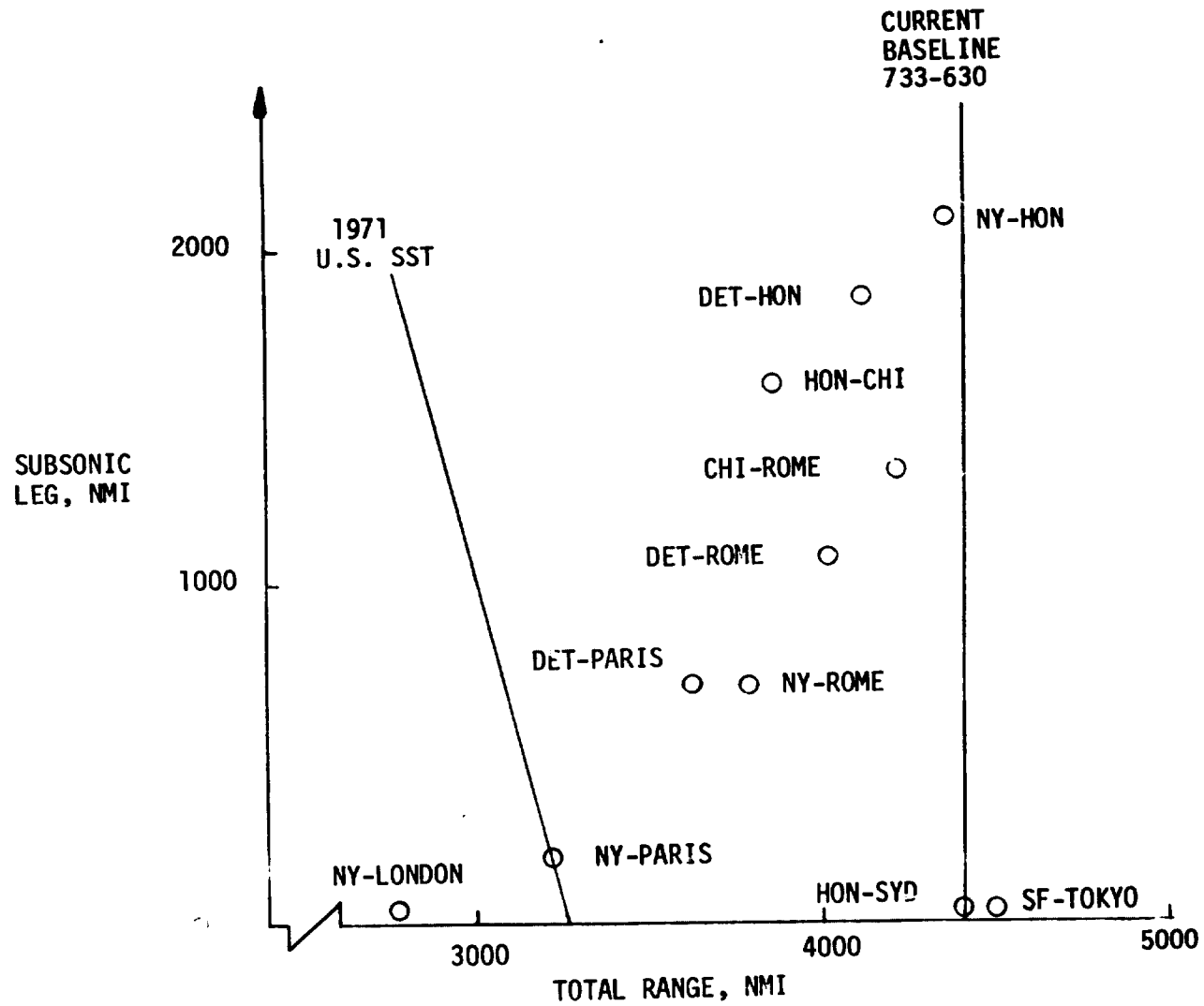


Figure 8. Boeing design approach and progress

DESIGN MACH NUMBER = 2.55  
WING AREA = 6720 FT<sup>2</sup>  
TAKE-OFF GROSS WEIGHT = 592000 lbs.  
PAYLOAD = 290 PASSENGERS  
RANGE = 3850 N. MI.

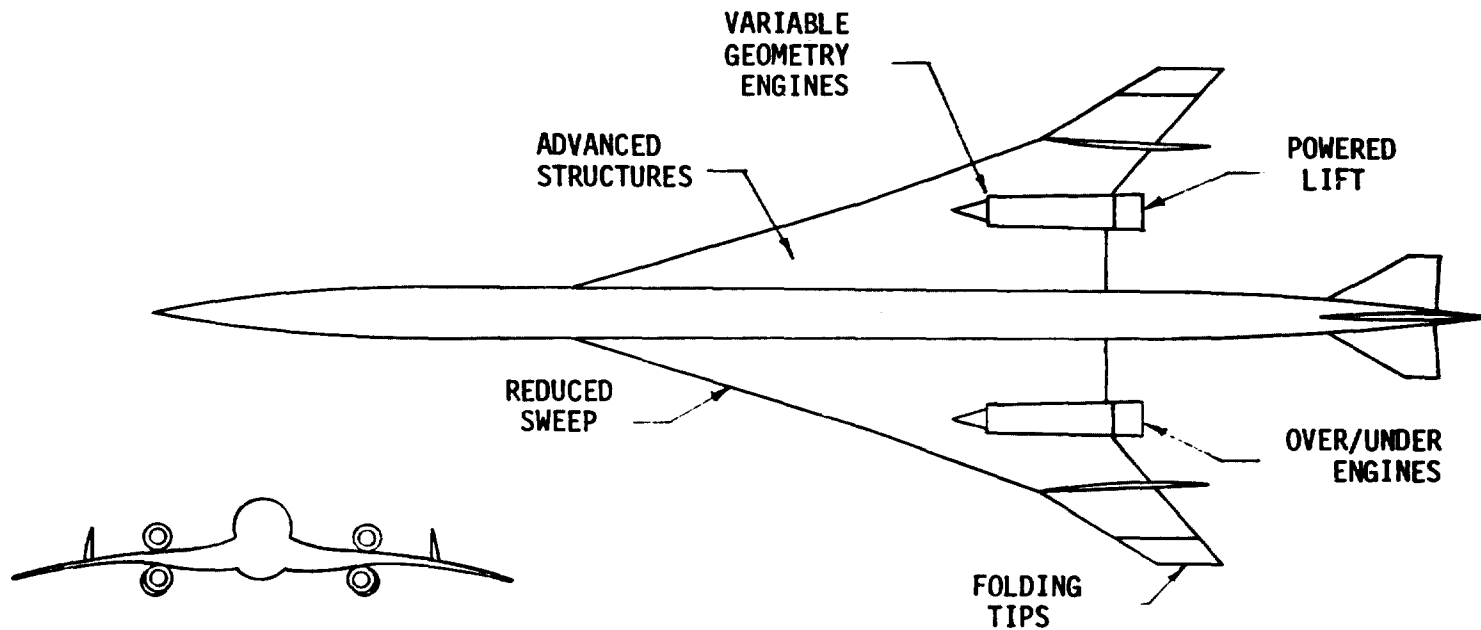


Figure 9. Lockheed baseline configuration

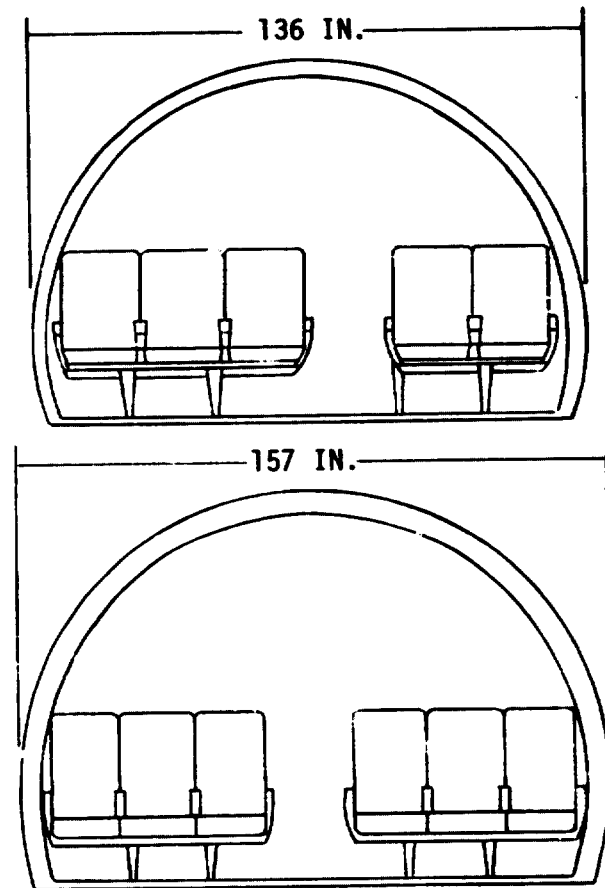
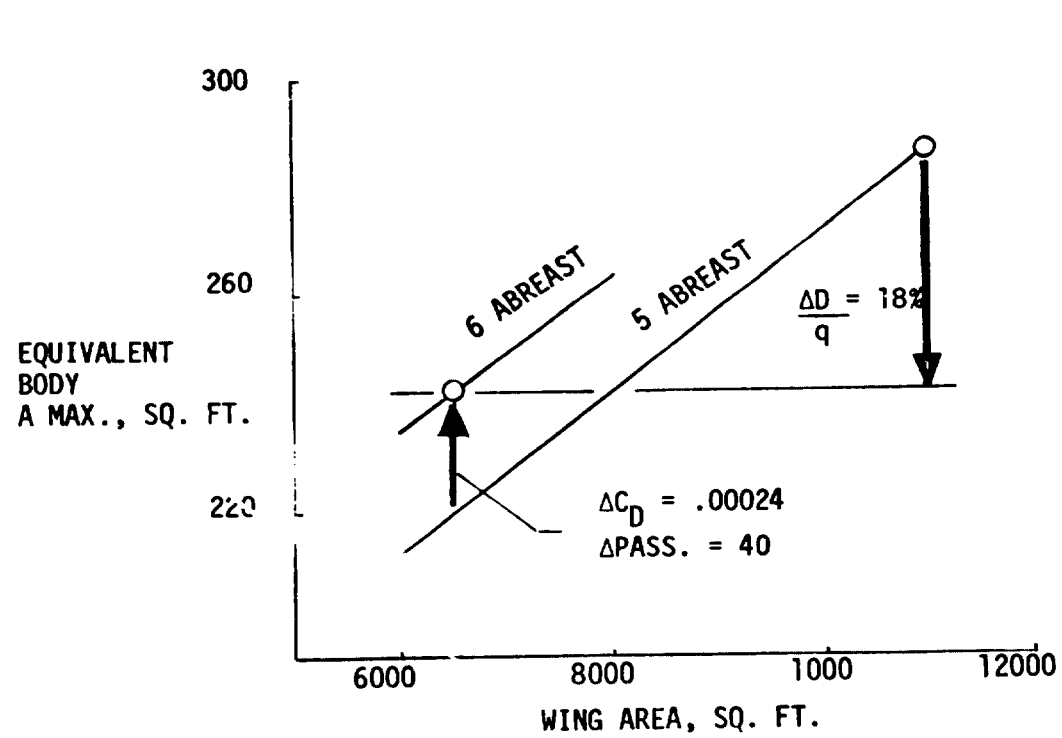


Figure 10. Lockheed passenger capacity increase

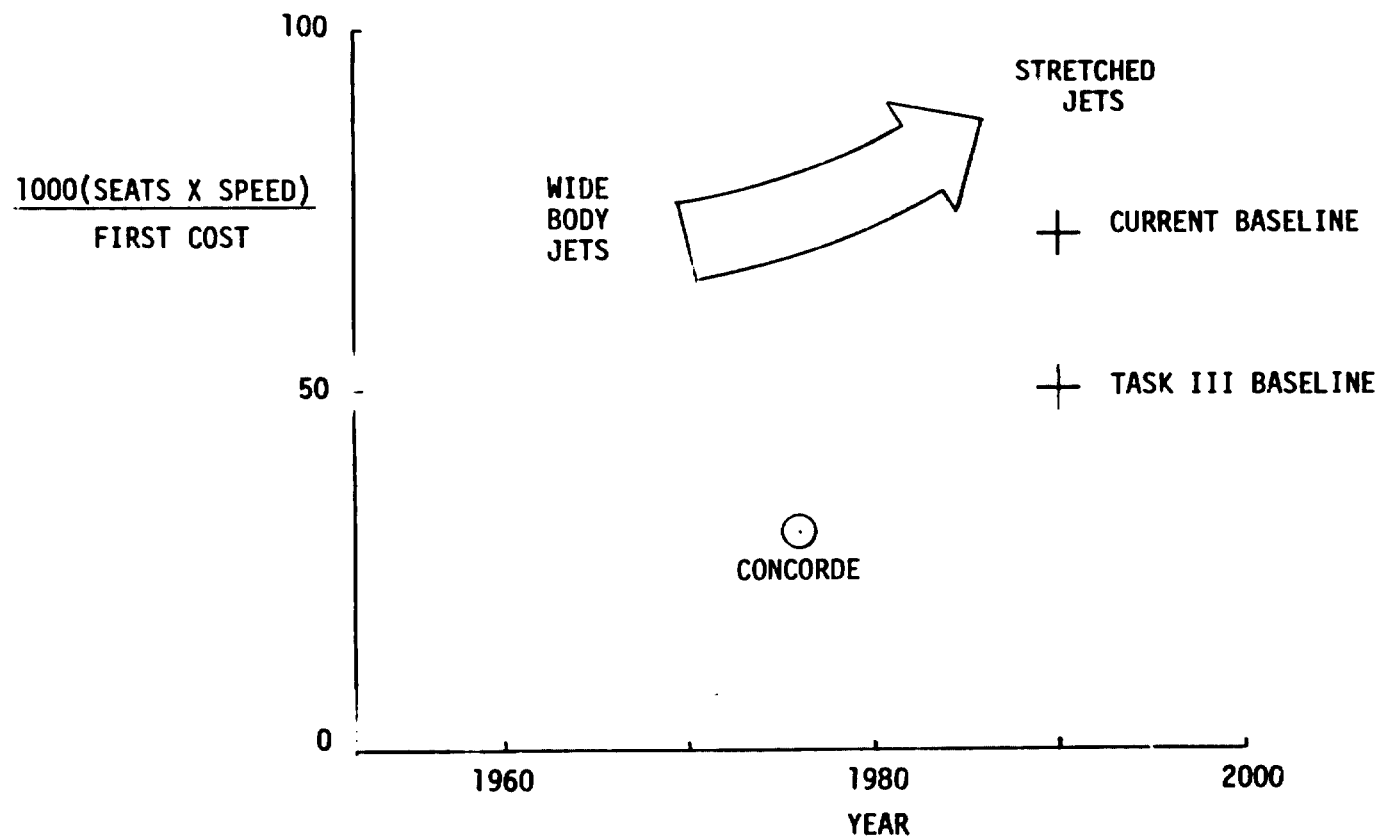


Figure 11. Lockheed progress - productivity and economics

## CRUISE MACH NUMBER STUDY

2.2 vs. 2.7

- 13 PERCENT LOWER DIRECT OPERATING COSTS
- 700 MILES MORE RANGE
- 150000 lb. LIGHTER
- 28 PERCENT LESS FUEL REQUIRED
- 40 PERCENT MORE PROFIT FOR AIRLINES
- 50 PERCENT GREATER MARKET
- MORE CURRENT STATE-OF-ART
- LOWER COST MATERIALS AND SYSTEMS
- 17 PERCENT HIGHER PAYLOAD FRACTION

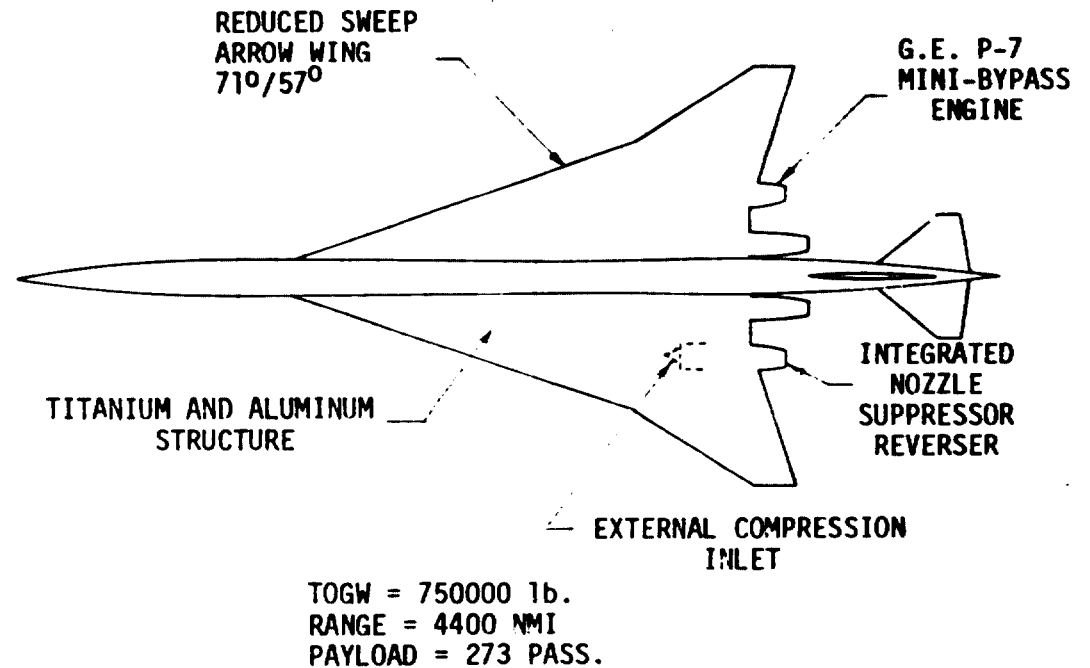


Figure 12. Douglas design considerations

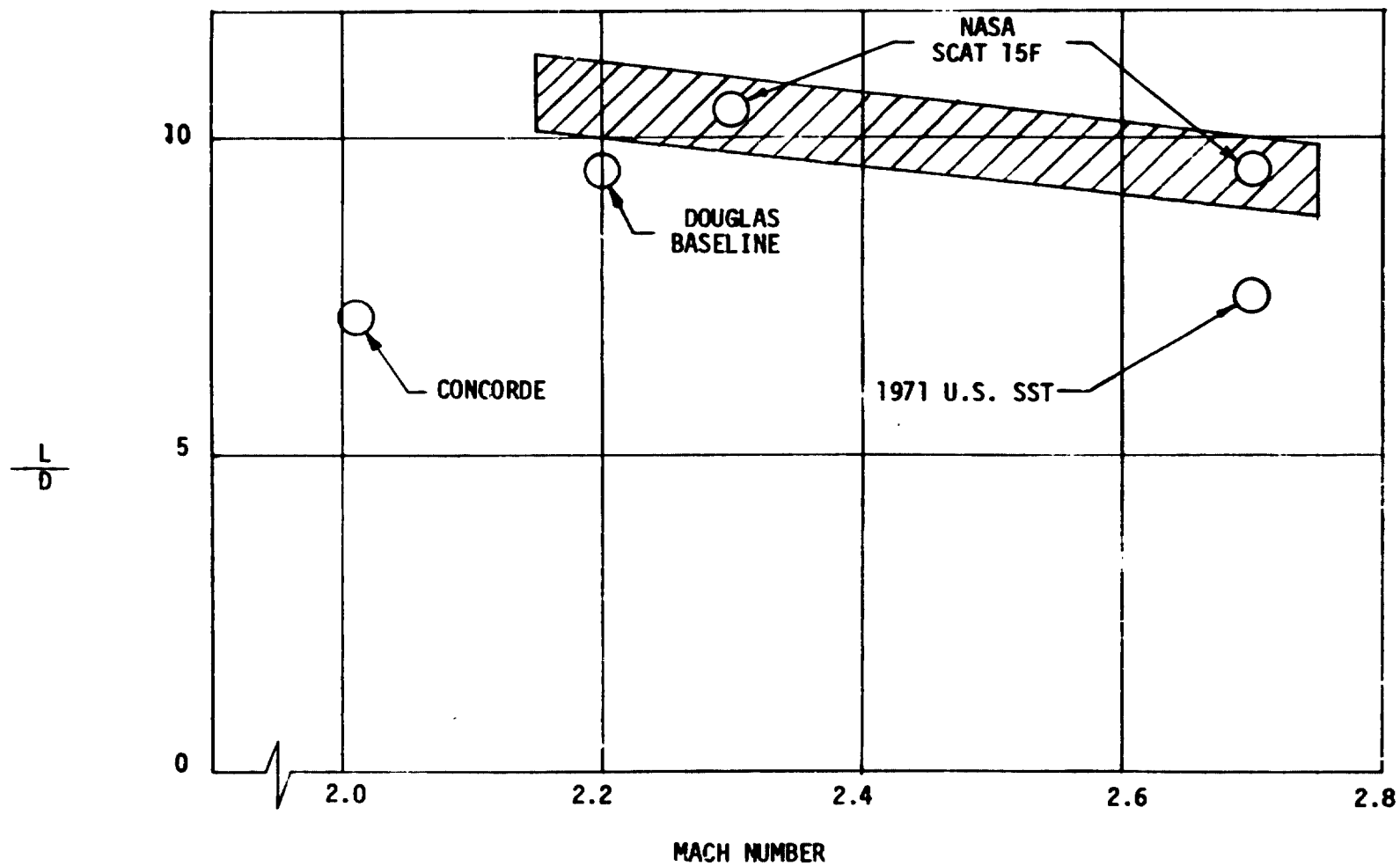


Figure 13. Douglas Aerodynamic results

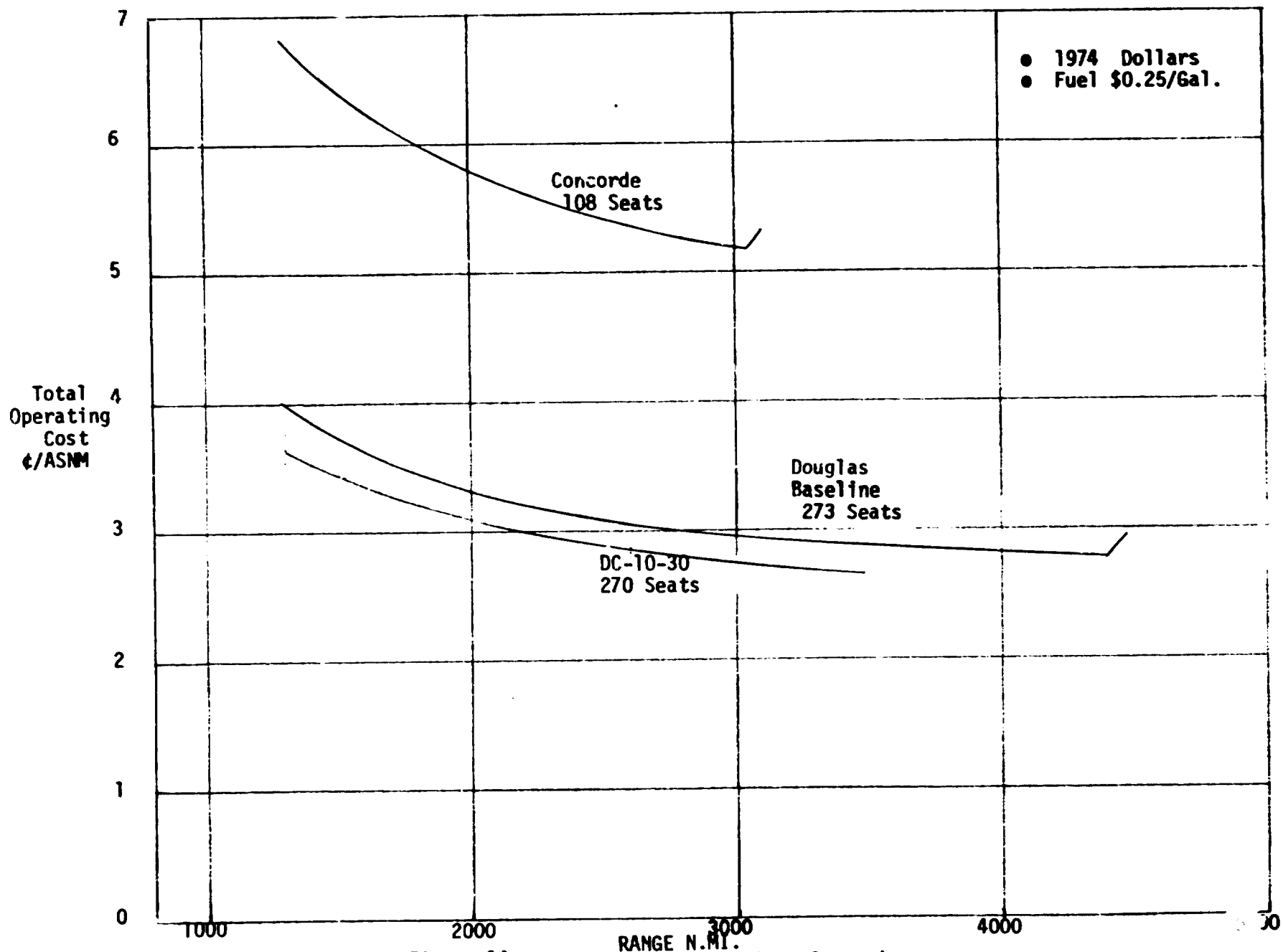


Figure 14. - Douglas Operating Cost Comparison

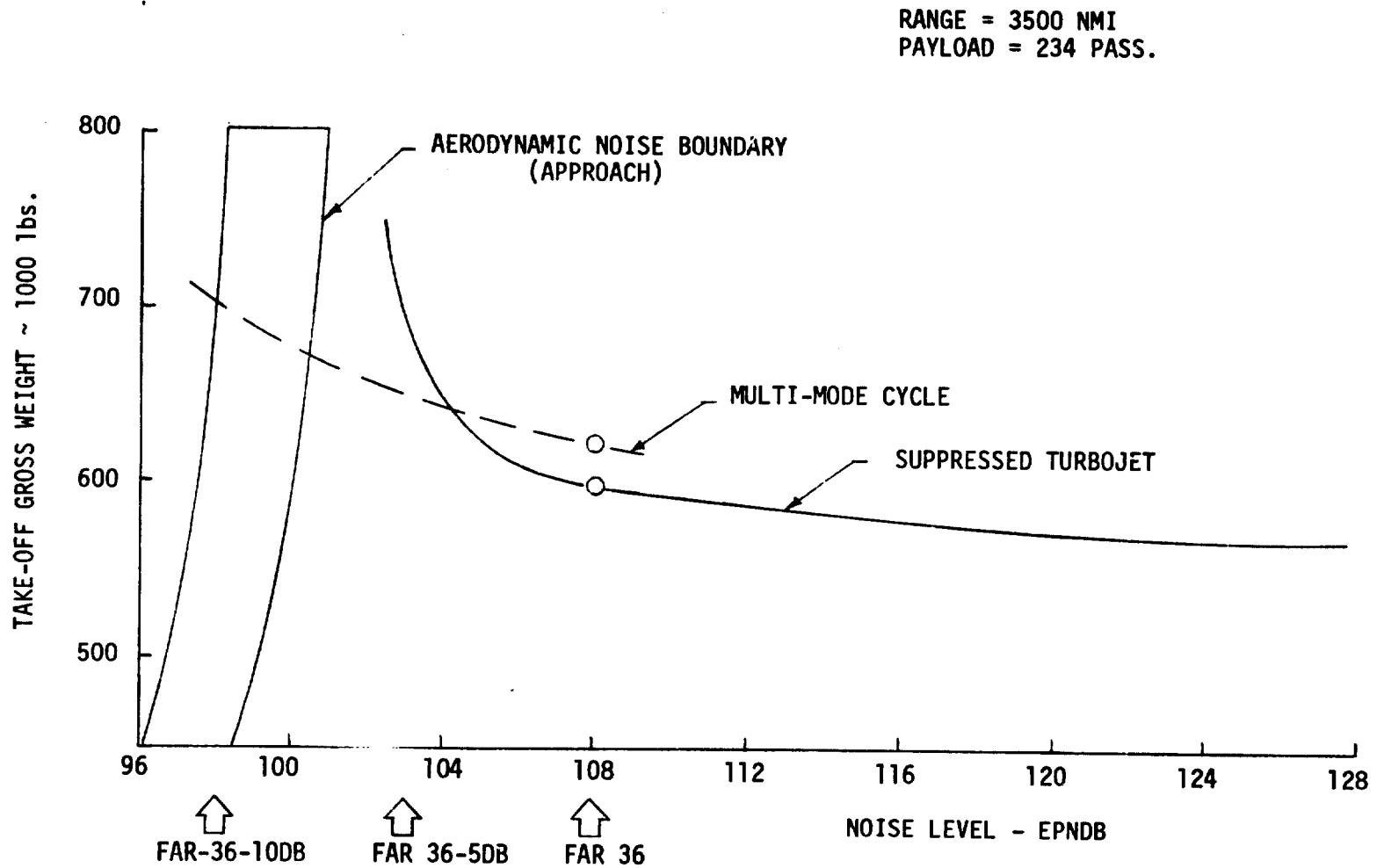


Figure 15. Results of Rockwell MMIPS Study

### REFERENCE AIRCRAFT DIFFERENCES

- CANARD REMOVED
- WING PLANFORM CHANGED AND INCREASED SPAN
- HORIZONTAL TAIL VOLUME INCREASED
- LEADING EDGE DEVICES SIMPLIFIED
- TRAILING EDGE FLAP SIZES INCREASED
- WING MOVED FORWARD
- HARD SAS WITH C.G. CONTROL
- PASSENGER CAPACITY INCREASE TO 292
- BODY LENGTH INCREASED
- BODY DIAMETER INCREASED
- LARGER DRY TURBOJET ENGINES
- LANDING GEAR SHORTENED
- WING THICKNESS MODIFIED

REFERENCE AIRCRAFT

336-C AIRCRAFT

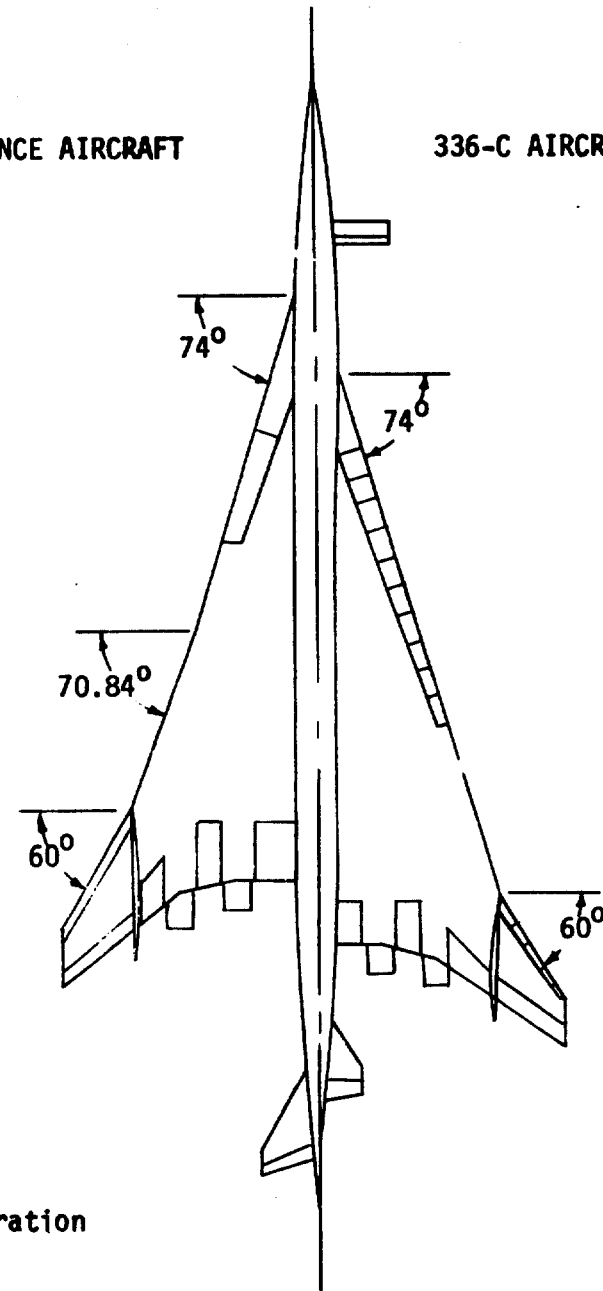


Figure 16. NASA/LTV Mach 2.7 reference configuration

RANGE, N.M.I.  
TOGW, LBS.  
SPEED  
MATERIAL  
ENGINE

CONCORDE  
2900  
40000  
M ~ 2.0  
ALUMINUM  
ABTJ

969-336C  
3800  
750000  
2.7  
TITANIUM  
DTJ (633 lb/sec.)

NASA/LTV REFERENCE  
4200  
760000  
2.7  
TITANIUM  
DTJ (800 lb/sec.)

PAYLOAD, LBS.  
~ 1000

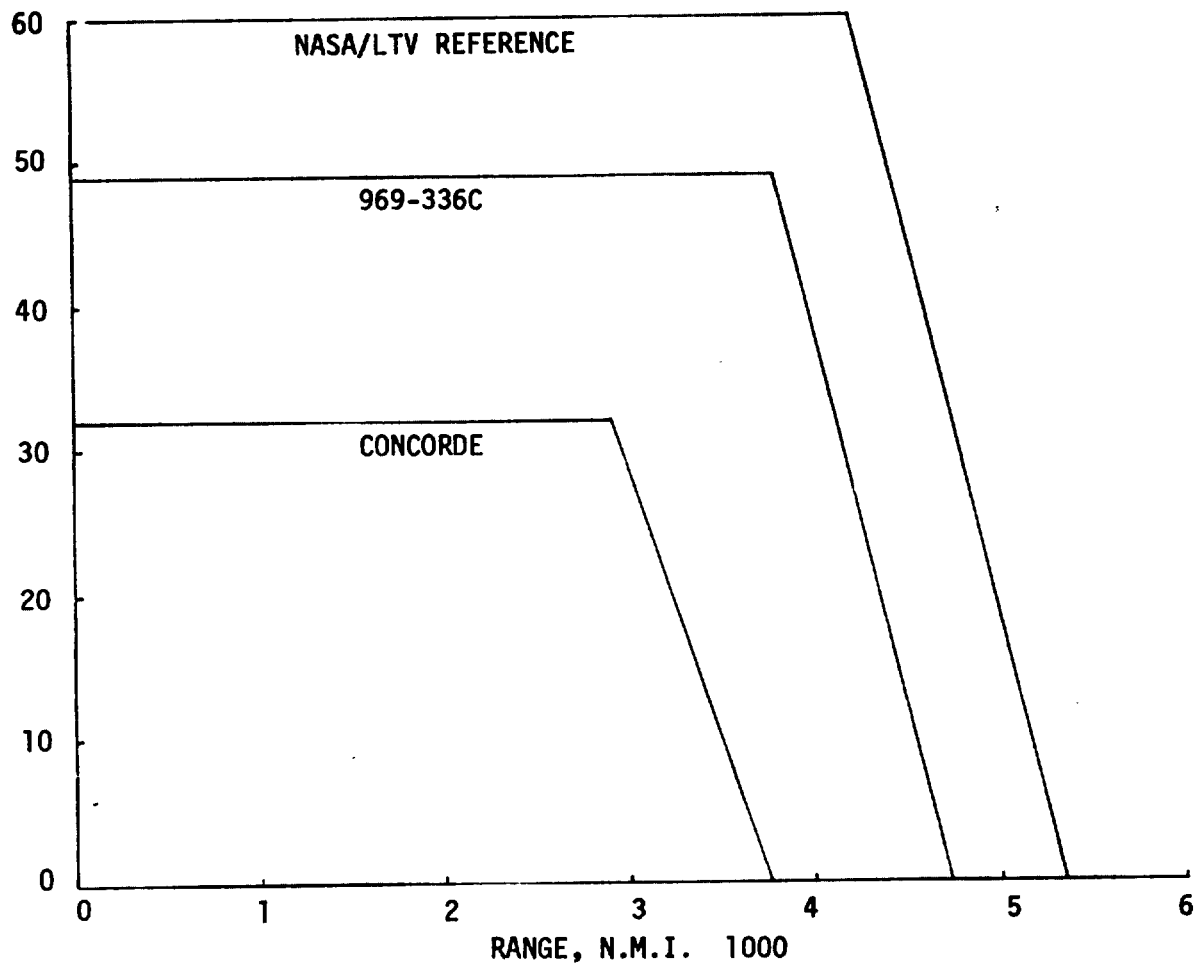


Figure 17. NASA/LTV reference configuration performance

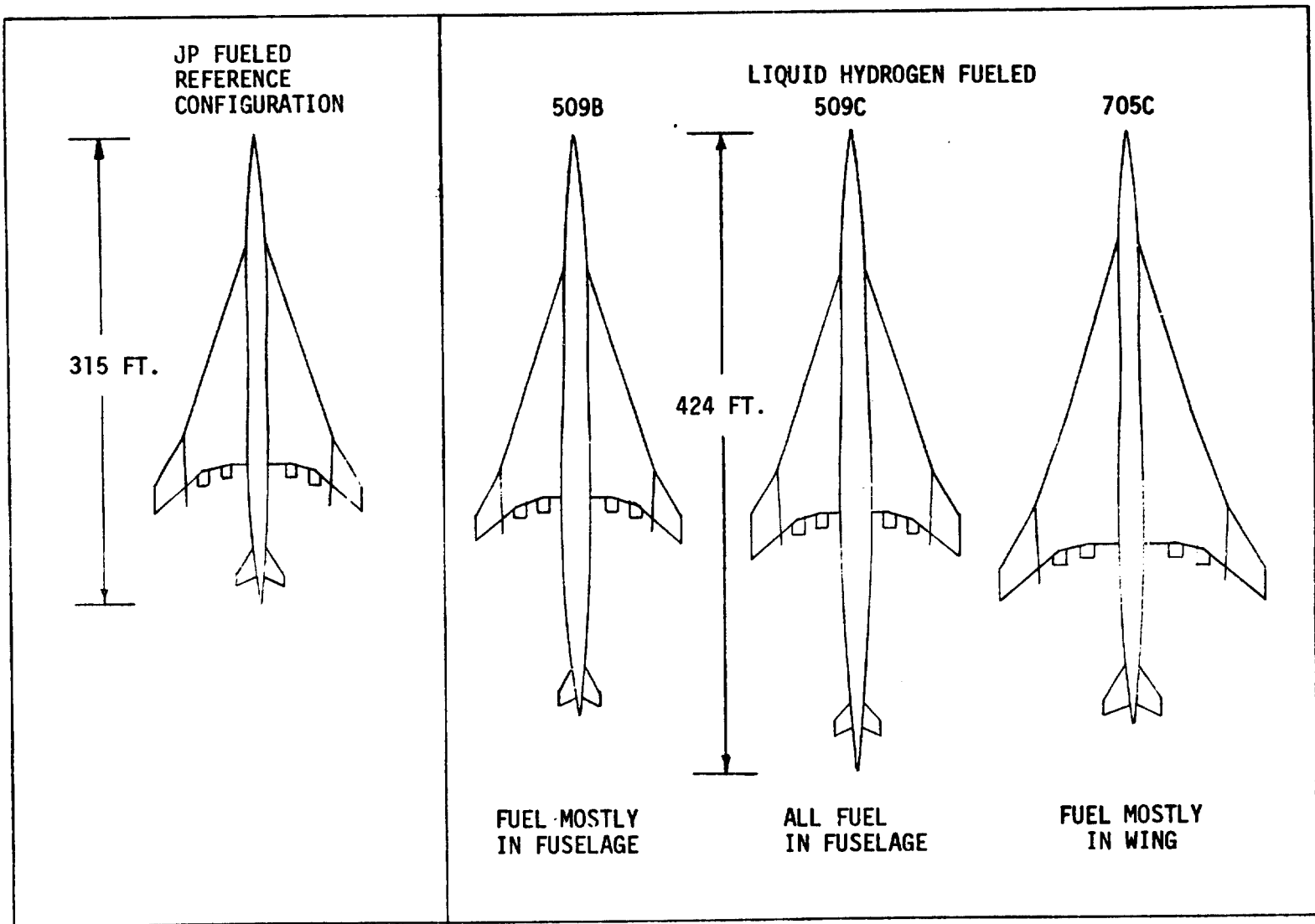


Figure 18. Liquid Hydrogen Study Configurations

RANGE ~ 4200 N.M.I.

NASA/LTV STUDIES  
(292 PASS.)

NASA/LOCKHEED STUDIES  
(234 PASS.)

○ 509B  
□ 509C  
◇ 705C

△

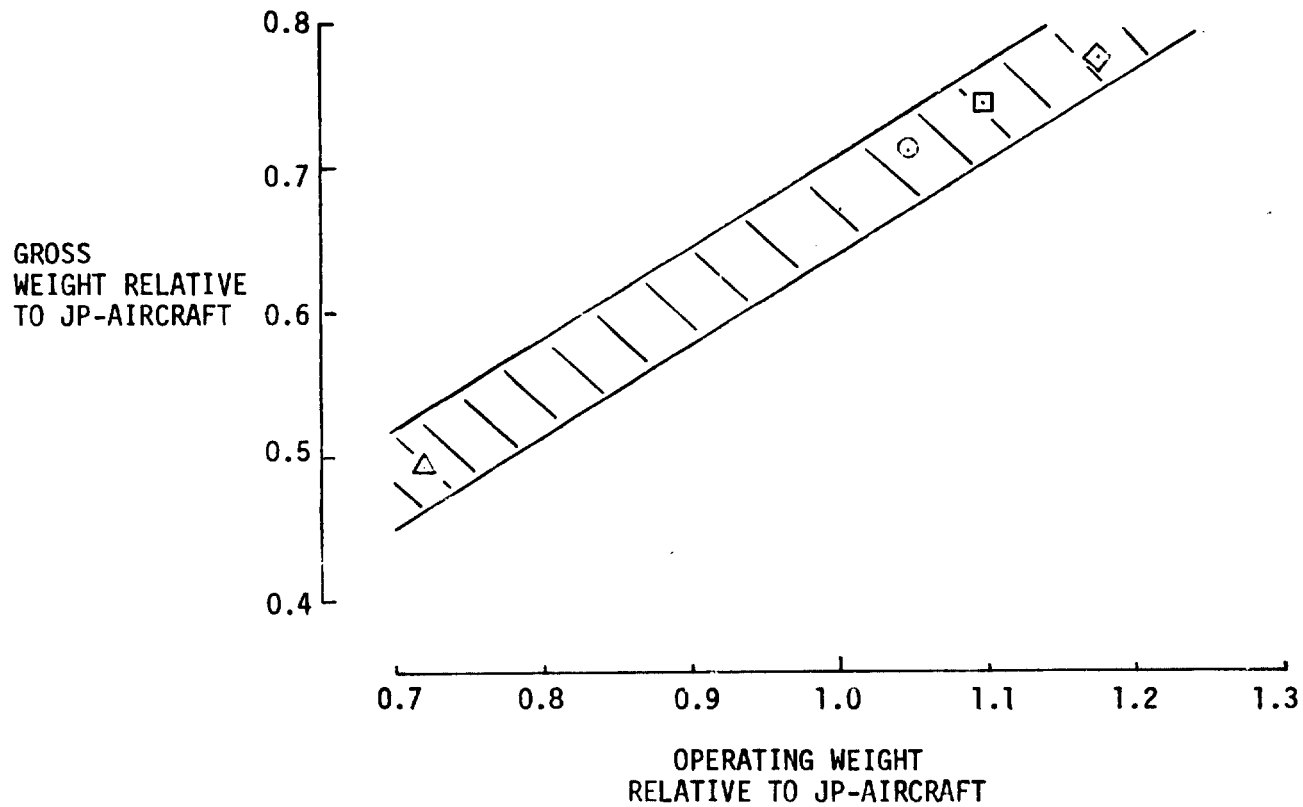


Figure 19. Liquid hydrogen configuration studies